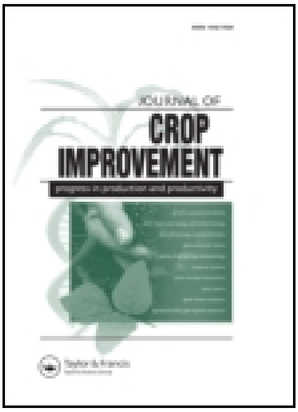

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*A better understanding of sugarcane (*Saccharum spp.*) genetic variability in agronomic performance will help optimize breeding and selection strategies. Vigor ratings and Brix data were collected from the 2009 and 2010 clones in the first clonal selection stage (stage I) of the Canal Point (CP) sugarcane cultivar development program. Stage I individual selection was based on disease resistance and on the product of vigor and Brix. Vigor ratings (from 1 to 9) from all clones and Brix of any clones with a vigor rating ≥6 were collected in the stage I fields and analyzed for relationships between vigor and Brix, for selection rate in each family (i.e., cross), and for their coefficients of variation (CV) within and among families. There was no correlation between vigor and Brix, suggesting that it would be feasible in stage I to select sugarcane*

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clones with both high vigor and high Brix. Variability was high (CV = 59%) for both the number of planted clones and selection rates among families, and vigor (7.2%) had greater CV than Brix (5.4%). Averaged across years, the within-family CVs (9.3% for vigor and 6.3% for Brix) were greater than the among-family CVs (6.3% for vigor and 4.7% for Brix). Results indicated that greater emphasis on family-based than on individual selection in stage I should be avoided, as it would result in the loss of potentially productive clones. However, use of individual selection data on vigor and Brix for analyzing family performance should improve parental selection and optimize crosses.

KEYWORDS *Sugarcane, early-stage selection, vigor rating, Brix, Canal Point (CP) sugarcane cultivar development program*

INTRODUCTION

Sugarcane (a complex hybrid of *Saccharum* spp.) is an important crop in Florida with an annual economic impact of more than $440 million (USDA-NASS 2009). Consistent and continuous development of high-yielding sugarcane cultivars with resistance or tolerance to biotic and abiotic stresses is critical to commercial sugarcane production in South Florida. The USDA-ARS Sugarcane Field Station at Canal Point (26.52°N; 80.36°W), Florida, was initially established at its present site in 1920 to conduct sugarcane breeding and selection for Florida and to make crosses and produce true sugarcane seed for the Louisiana sugarcane industry. Since the 1960s, the Canal Point station has been developing sugarcane cultivars with CP prefixes for Florida under a three-party cooperative agreement among the USDA-ARS, the University of Florida, and the Florida Sugar Cane League Inc. Also, the Canal Point station makes crosses for the USDA-ARS in Houma, Louisiana, and the Texas A&M University program at Weslaco, Texas. The CP cultivars now account for more than 95% of the hectarage in Florida, up from 14% in 1970 (unpublished data). In 2008, the top six major sugarcane cultivars grown in Florida were 'CP 89-2143' (Glaz et al. 2000), 'CP 88-1762' (Tai et al. 1997), 'CP 80-1743' (Deren et al. 1991), 'CP 78-1628' (Tai et al. 1991), 'CP 72-2086' (Miller et al. 1984), and 'CP 84-1198' (Glaz et al. 1994), and their percent hectarages, respectively, were 31.0%, 20.3%, 18.8%, 10.9%, 3.8%, and 3.6% (Rice, Baucum, & Glaz 2009).

The CP sugarcane cultivar development program consists of six stages, namely crossing, seedlings, and stages I, II, III, and IV (Figure 1). It takes at least eight years to release a cultivar from the time a cross is made (Tai & Miller 1989). Sugar content (kilograms of sugar per metric ton of cane), cane yield (metric tons of cane per hectare), and sugar yield (metric tons of sugar per hectare) are the major agronomic traits considered in advancing sugarcane clones during the selection stages. Edmé et al. (2005) reported that sugar content, cane tonnage, and sugar yield of Florida commercial sugarcane cultivars linearly increased by 26.0%, 15.5% and 47.0%, respectively, from 1968 to 2000. Underscoring the critical need for cultivar development for the Florida sugarcane industry, about 69% of the sugar yield gain in Florida was from genetic improvement attributable to the CP cultivar development program (Edmé et al. 2005).

There are approximately 70,000 and 10,000 genotypes planted annually in the seedling stage and stage I of the CP program, respectively (Figure 1). As is characteristic of many selection programs, it is not considered prudent to use limited resources to quantitatively measure yields for these large numbers of genotypes or clones in early stages. Therefore, selection in stage I is based on subjective assessments of plant vigor, along with disease assessments in early September and measurements of Brix in early November.

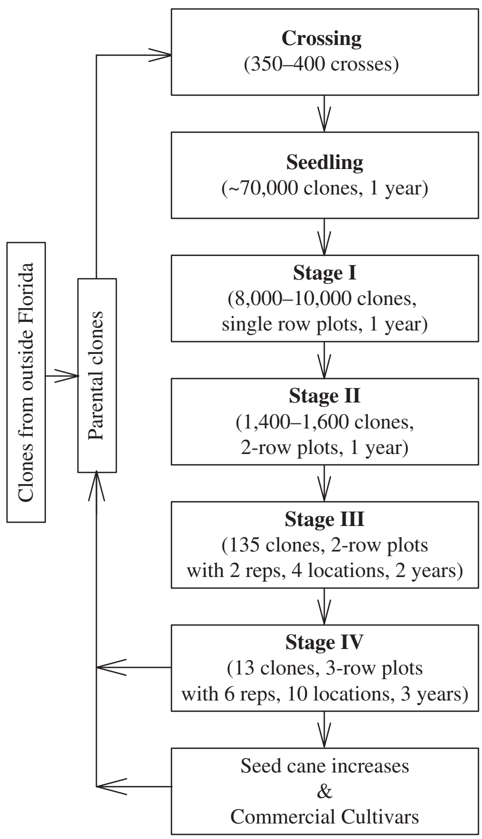


FIGURE 1 A Flowchart Describing the Cooperative Sugarcane Breeding and Genotype Selection Program that Develops Canal Point (CP) Sugarcane Cultivars.

Variability of vigor rating and Brix in stage I among and within families is not well documented, and programs rarely distinguish between them at the practical level (Simmonds 1996). The selection of which sugarcane clones to use as parents is a critical decision for breeders. Consequently, knowledge and better understanding of variability in vigor and Brix may provide useful information for genotype advancement and for efficient use of parents in future crossing efforts. Therefore, a study was conducted in the stage I fields of the CP cultivar development program at the USDA-ARS Sugarcane Field Station, Canal Point, Florida. The objectives of the study were to determine variability in plant vigor and stalk-juice Brix based on data collected from the stage I clones of the CP program in 2009 and 2010 and to use this information in parental selection and cross appraisal.

MATERIALS AND METHODS

Individual stalks of 9,520 genotypes in 2009 and 8,504 genotypes in 2010 were visually selected from fields of the 2008 and 2009 seedling stages (Figure 1) and planted in single-row plots in the stage I fields in late January of 2009 and 2010, respectively. To facilitate stalk transport and planting, two to five stalks (each stalk came from a true seed) in the seedling fields were bundled and labeled by family (i.e., progeny of the cross from a female and male) prior to advancing them to stage I. These bundles were randomly distributed in the stage I fields. One stalk was placed in each plot and cut into two sections (each approximately 0.8 m long). The two sections were placed in the center of the plot as double lines of cane. The plot length was 2.4 m, with a 1.5-m between-row spacing. There was a 1.6-m gap between adjacent clones within a row to allow selectors to recognize individual clones during evaluation and selection and to easily distinguish selected individuals. Four commercial cultivars (‘CP 78-1628’, ‘CP 80-1743’, ‘CP 88-1762’, and ‘CP 89-2143’) were used as checks each year and randomly planted in approximately every 200 plots. There were 18 to 28 replicated plots for each check. There was a 4.5-m alley every eight rows to facilitate field maintenance and genotype selection.

All clones were visually evaluated on the basis of disease resistance and cane yield traits (stalk number, height, and diameter). Disease resistance to brown rust (*Puccinia melanocephala*), orange rust (*Puccinia kuehnii*), leaf scald (*Xanthomonas albilineans*), smut (*Sporisorium scitamineum*), and mosaic was evaluated annually in August. Cane yield traits and late-season disease status were rated annually in early September. A subjective vigor rating, which was an overall indicator of cane yield traits, was determined for individual clones using a scale from 1 (worst) to 9 (best). Rust diseases were recorded under natural infection using a scale from 0 (no rust infection) to 4 (most severe rust infection). In 2009, clones that had brown or orange rust rating ≥2 were not rated for vigor, but all clones were rated for vigor in 2010. All clones with a vigor rating ≥6 and acceptable disease resistance (rust rating <2) were further assessed for Brix. Brix of stalk juice, an indicator of sucrose content, was measured from each clone using a handheld refractometer (REF103/113, National Microscope Exchange Inc., WA) in early November. Juice used for Brix was collected from an inter-node located in the middle of the stalk with a handheld punching device. Approximately 1,500 clones with the largest vigor × Brix products were advanced to stage II (Figure 1).

For the four check cultivars, replicate plots were completely randomized in the stage I field each year. The MIXED procedure of SAS (SAS Institute Inc., Cary, NC) was used to test differences of cultivar, year, and their interaction for vigor rating and Brix. If the hypothesis of equal means between the cultivars was rejected by the *F* test, trait means were separated with the LSD at $p = 0.05$. The LSD values were calculated with the SE values generated by the Diff option in the SAS MIXED procedure. The variance components and coefficients of genetic variation (CGV) for vigor rating and Brix for the four check cultivars were calculated based on the trait genetic variance (*Vg*) and trait mean ($\overline{X}$) as following Houle (1992):

$$\mathrm{CGV} = 100 \times \sqrt{V_g} \div \overline{X}$$

For the stage I clones, their parental combinations in the crossing stage varied annually. Thus, the stage I data were analyzed separately for each year. Vigor rating distributions and relationships between vigor ratings and Brix values were determined by pooling data across all clones within a year. Many of the progeny in the 2009 and 2010 stage I were from polycrosses (i.e., where a female tassel received pollen from several different male tassels). Data of final selection rate (defined as the number of selected clones divided by total number of clones planted for each family × 100), vigor, and Brix were analyzed for each family. Variance components (i.e., genotype and environment or error) across families for vigor rating and Brix were determined using the SAS PROC VARCOMP procedure, and each CGV was estimated according to Houle (1992).

For families that had ≥15 clones planted, the coefficients of variation (CVs) were determined for vigor and Brix to assess their variability. Means and CVs for vigor and Brix were calculated using PROC MEANS of SAS. Coefficients of variation for Brix and vigor of each family were calculated from the individual clonal values of vigor and Brix from all clones within a family. Then, the within-family CV for each parameter was estimated by calculating the overall mean CV of all individual family CVs for that trait. The among-family CVs were estimated using the mean (rather than individual clonal values) values of each family. For example, to calculate the among-family CV of 20 families for Brix, we calculated the CV based on the standard deviation and overall mean from the 20 mean Brix values of each of the 20 families. The variability among and within families was described using respective CVs. The top 20 families in each year were further determined based on their selection rates.

RESULTS AND DISCUSSION

A total of 9,615 and 8,595 clones, including 95 and 91 checks, were planted in stage I fields in 2009 and 2010, respectively. Emergence and stands were poorer in 2009 than in 2010. At vigor scoring dates (early September), there were 1,266 plots (13.2%) with no plants in 2009, but only 112 plots (1.3%) lacked plants in 2010. The poor stands in 2009 were probably associated with a six-hour freeze (−4 to −6°C) on 21 January 2009 prior to planting in the field, which likely injured buds, resulting in poor emergence because sugarcane buds (growing points) immediately became soft and discolored after frost (Ranger, Gulotti, & Montagu 1969).

Performance of Check Cultivars

For the four check cultivars, there was no significant difference between years in vigor rating, and the cultivar × year interaction was also not significant (Table 1). Significant differences were detected in the vigor ratings among the check cultivars; averaged across years, CP 80-1743 had a significantly lower vigor rating than CP 88-1762 and CP 89-2143. Vigor ratings of the four check cultivars ranged from 5.5 to 6.7 in 2009 and from 5.6 to 6.0 in 2010. Mean vigor ratings of the four checks in 2009 and 2010 were 6.1 and 5.9 with CVs of 26% and 17%, respectively. Brix was measured only on clones with acceptable disease ratings and vigor ratings ≥6. Brix values did not differ among the four checks and between the two years, and cultivar means ranged from 18.5 to 19.5 (Table 1). The CVs (4% to 9%) of Brix among replicated plots within each check were much smaller than the CVs (12% to 31%) of vigor rating. The higher CV for vigor rating than for Brix indicated that Brix was a more stable trait and was less influenced by the micro-environment. The coefficient of variation for each of the four check cultivars was a measure of that cultivar's variability across the replicated plots. Therefore, the CV for a check cultivar was mainly associated with micro-environment and random variation; there were no genetic components of variability in each of these CVs. Estimates of variance components and CGV for vigor rating across the four check cultivars revealed that the percentages of variances contributing from genotype, genotype × year interaction, and experimental error were 23%, 54%, and 23%, respectively. The genotypic contribution for Brix among the four check cultivars was low (12%), because Brix did not differ among the check cultivars (Table 1).

TABLE 1 Field Performance of Four Check Cultivars Tested with Sugarcane Clones in the Stage I Field of the Canal Point (CP) Sugarcane Cultivar Development Program in 2009 and 2010

	Vigor†			Brix‡		
Cultivar	Clone #	Mean	CV (%)	Clone #	Mean	CV (%)
2009						
CP 78-1628	28	6.1	29	6	19.5	8.4
CP 80-1743	23	5.5	31	9	18.7	6.6
CP 88-1762	18	6.7	21	11	19.1	6.0
CP 89-2143	26	6.5	22	16	18.5	9.4
Mean	24	6.1	26	11	18.8	7.6
2010						
CP 78-1628	18	5.6	18	10	18.8	7.1
CP 80-1743	23	5.9	19	11	18.7	7.5
CP 88-1762	24	6.0	12	7	19.2	4.4
CP 89-2143	26	5.9	18	15	19.0	6.3
Mean	23	5.9	17	11	18.9	6.3

		Pr > F	
Effect	DF	Vigor	Brix
Cultivar	3	0.0392	0.4917
Year	1	0.1171	0.1138
Cultivar × Year	3	0.1803	0.5556

†Clones with rust rating ≥2 were not used to evaluate vigor in 2009 and the number of dead clones is not included in "Clone #."
‡Brix was measured only for clones with vigor ≥6 and rust rating <2.

Distribution of Vigor Rating

The numbers of clones used for vigor ratings were 6,392 in 2009 and 8,483 in 2010. These included 95 and 91 checks in 2009 and 2010, respectively (Figure 2). It is noted that each clone with rust rating ≥2 was not rated for vigor in 2009, but all clones were rated for vigor in 2010. Distributions of vigor ratings based on the number of clones (Figure 2a) and on the percentage of total clones (Figure 2b) followed the normal distribution. Although the peak frequency of the vigor distribution was at 5 and the overall vigor mean was also approximately 5 in both years, the peak values in 2010 were greater than those in 2009 (Figure 2). The CVs of vigor ratings across 6,392 and 8,483 clones in 2009 and 2010 were 35% and 28%, respectively (Figure 2a). The variability (i.e., CV) across clones in a field within a year was mainly due to both genetic and micro-environmental factors. A wide range (from 1 to 9) with greater variability in the vigor ratings among clones (CV = 28%–35%), compared with the check cultivars (CVs = 17%–26%, Table 1), may allow us to select elite genotypes with vigorous growth for new cultivar development, although other environmental factors could not be eliminated.

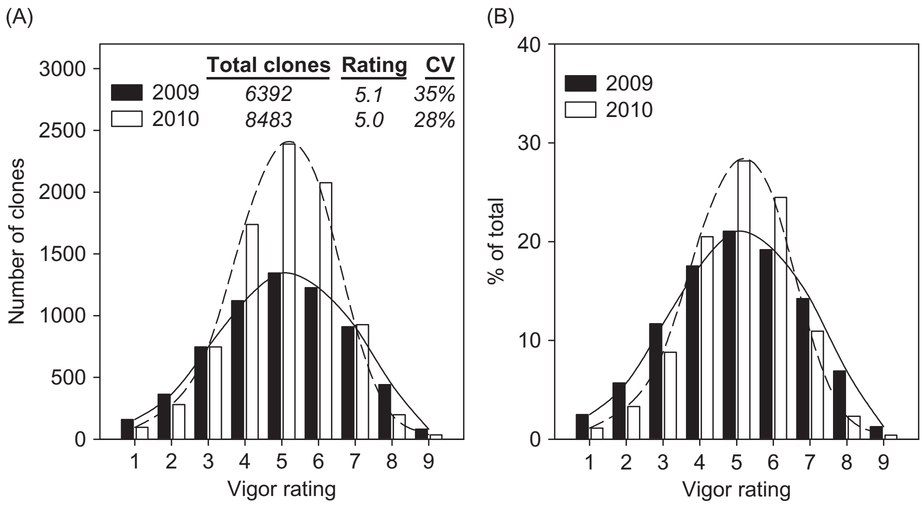


FIGURE 2 Distributions of Vigor Ratings Based on: (A) The Number of Clones and (B) the Percentage of Total Clones for Each Vigor Rating in Stage I of the Canal Point (CP) Sugarcane Development Program in 2009 and 2010.

Note: Plant vigor rating was carried out in early September. The number of clones used for vigor scoring in 2009 and 2010 include 95 and 91 check plots, respectively. Clones with rust rating ≥2 were not rated in 2009. Vigor ratings from 1 to 9 indicate from the worst to best in cane yield potential.

Variability in the Number of Clones and Vigor Rating Among Families

Total crosses (families) advanced to stage I from the seedling stage by individual selection were 426 and 359, respectively, in 2009 and 2010. Clone numbers among families ranged from 1 to 167 in 2009 and from 1 to 139 in 2010 with CVs of 122% and 99%, respectively (Table 2). This substantial variability in the number of clones among families was probably associated with (1) differences in the number of viable seeds per cross in the crossing stage, and/or (2) selection rate was low in the seedling stage for some families that had poor performance (Figure 1). On a family basis, vigor ratings ranged from 1.0 to 7.0 in 2009 and from 1.0 to 7.3 in 2010. Among-family CVs of vigor ratings were 46.4% and 17.5% in 2009 and 2010, respectively, and within-family CVs were 65.9% in 2009 and 27.8% in 2010. Large variability in the number of clones and in vigor rating (Table 2) among families in stage I of the CP program suggested that, although stage I data could be used to identify useful parental combinations and individual parents, this information needs to be used cautiously. The greater CV for vigor within families than among families suggested that placing more emphasis on both individual clonal evaluation and family-based evaluation in stage I of the CP program may help improve our ability to select genotypes with high biomass potential. Coefficient of genetic variation is an estimate of genetic variability. The CGV could not be calculated for clones within a family due to the

TABLE 2 Maximum (Max), Minimum (Min), Mean, Standard Deviation (SD), and Coefficient of Variation (CV) for Clone Number and Vigor Rating of 426 (in 2009) and 359 (in 2010) Sugarcane Families with a Total of 8,254 and 8,392 Clones, Respectively, Tested in the 2009 and 2010 Stage I Fields in the Canal Point (CP) Sugarcane Cultivar Development Program

	2009		2010	
Parameter	Clone (No. family^{-1})	Vigor†	Clone (No. family^{-1})	Vigor
Max	167	7.0	139	7.3
Min	1	1	1	1
Mean	19.8	3.7	23.3	4.8
SD	24.2	1.7	23.0	0.8
CV (%, among families)	122.3	46.4	99.1	17.5
CV (%, within families)	–	65.9	–	27.8

†The numbers of clones used for vigor scoring in 2009 are 6,297 because clones with rust rating ≥2 were not rated in the first year.

TABLE 3 Means, Genetic Variance Across Families, Remaining Variance, Coefficient of Genetic Variation (CGV) Across Families, and Coefficient of Variation (CV) From Remaining Factors for Vigor Rating and Brix in 2009 and 2010†

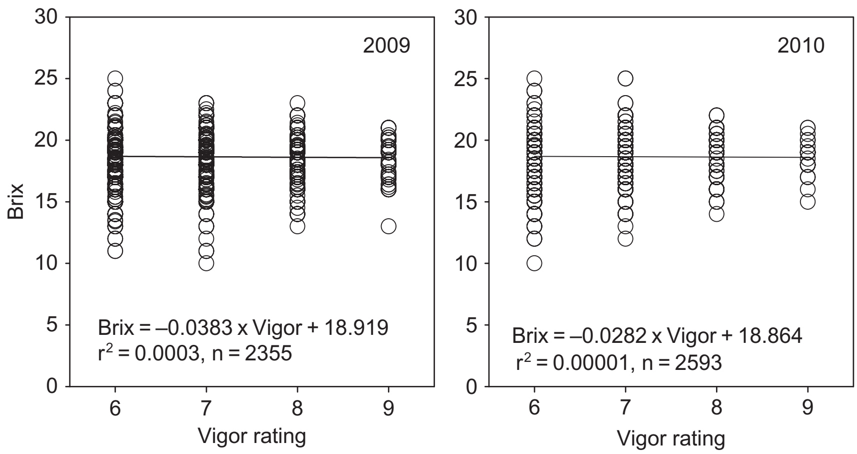
	Vigor rating (1)		Vigor rating (2)		Brix	
Parameter‡	2009	2010	2009	2010	2009	2010
Mean	5.05	5.03	6.76	6.48	18.66	18.67
Genetic variance across families (Vg)	0.339	0.167	0.043	0.055	0.251	0.510
Remaining variance (Vr)	2.789	1.822	0.648	0.404	2.941	2.333
CGV across families	11.53	8.13	3.06	3.62	2.68	3.83
CV from remaining factors	33.05	26.85	11.91	9.81	9.19	8.18
CGV/(CGV+CV)×100	25.86	23.24	20.44	26.95	22.58	31.89

†Data of vigor rating (1) include all clones, but data of vigor rating (2) are based only on the clones with Brix data collection (vigor rating ≥6).
‡CGV across families = $100 \times \sqrt{V_g} \div$ mean; CV from remaining factors = $100 \times \sqrt{V_r} \div$ mean.

non-replicated data in stage I of the CP program. Coefficients of genetic variation for vigor rating across families for all clones in 2009 and 2010 were 11.53 and 8.13, respectively, which accounted for 23%–26% of the total CV (Table 3). These results indicated that genetic variability accounted for a substantial portion of the variability in the vigor ratings.

Correlation Between Vigor and Brix

Of the 426 (2009) and 359 (2010) families planted in stage I, there were 305 and 292 families, respectively, having at least one or more clones with a vigor rating of ≥6. From these high-vigor families and check cultivars Brix was measured on 2,355 and 2,593 clones, respectively, in 2009 and 2010. Overall, Brix values ranged from 10 to 25 each year (Figure 3). Mean vigor ratings for these clones were 6.8 in 2009 and 6.5 in 2010, and the mean



Parameter	Vigor = 6		Vigor = 7		Vigor = 8		Vigor = 9	
	2009	2010	2009	2010	2009	2010	2009	2010
Total #	1089	1578	804	808	393	176	69	31
Max. Brix	25	25	23	25	23	22	21	21
Min. Brix	11	10	10	12	13	14	13	15
Mean Brix	18.7	18.7	18.7	18.7	18.6	18.5	18.4	18.6
CV (%)	9.8	9.2	9.6	8.6	9.0	8.5	8.8	7.2

FIGURE 3 For Clones with a Vigor Rating of ≥ 6, Correlation of Brix with Vigor Rating and Variation of Clone Numbers, the Maximum (Max), Minimum (Min), and Mean Brix and CV for Brix at Each Vigor Rating for Stage I of the Canal Point (CP) Sugarcane Development Program in 2009 and 2010.

Brix value was 18.7 in each year (Table 3). The CGV for vigor rating across families in 2009 and 2010 were 3.06 and 3.62, respectively, and 2.68 and 3.83, respectively, for Brix (Table 3). Averaged across years, CGVs of vigor rating and Brix across families accounted for 21.5% and 29.5% of the total variation in their respective CVs (Table 3). These results suggested that, at the family level, genetic contribution was more for Brix than for the vigor rating.

There was no significant relationship between Brix and vigor in either year (Figure 3). This indicated that during early sugarcane clonal selection, such as stage I, there is no tradeoff between vigor and Brix, and that it may be feasible to select for sugarcane genotypes with both high potential of cane yield and high sucrose content. Similarly, no significant correlation was found between cane yield and sucrose content among 23 series of stage II clones of the CP program (Glynn et al. 2009). Jackson, McRae, and Hogarth (1995a) also reported that serious reductions in cane yield would be unlikely as a result of independent selection for sucrose content. However, Glynn et al. (2009) reported a significant, negative correlation between cane yield and sucrose content among genotypes tested in stage III of the CP program when data were pooled across different locations with varied soil types (organic and sand soils), indicating that environment (especially soil properties) may affect correlations between cane yield and Brix. Sugarcane plants on sandy soils are subjected to earlier and more severe water-deficit stress than those on organic soils (Zhao, Glaz, & Comstock 2010) during a dry period. The water stress can reduce plant growth and result in condensing sugar content.

Variability in Clonal Numbers, Vigor, and Brix Among Families

Based on the product of vigor ratings and Brix values (i.e., vigor × Brix), 1,423 and 1,501 clones were selected to advance to stage II, respectively, in 2009 and 2010. These selected clones were unevenly distributed across 251 (2009) and 263 (2010) families (Table 4). Further analyses of variability in the number of clones selected, vigor, and Brix among these families indicated that the number of selected clones per family had the most variability (CV = 99%–114%) and Brix had the least variability (CV = 5.0%–5.8%). Averaged across families, mean vigor ratings of selected clones were 7.0 in 2009 and 6.7 in 2010. Mean selected clones per family (5.7), as well as mean Brix values (19.5), were the same for both years (Table 4). The mean vigor and Brix of selected clones were greater than those of the check cultivars in stage I in both years (Table 1).

Evaluation of Families Based on Selection Rates

Families with ≥15 clones were used to evaluate family performance. There were 165 and 176 families that had ≥15 clones planted in stage I, respectively, in 2009 (Table 5) and 2010 (Table 6). Wang et al. (2008) suggested

TABLE 4 Number of Clones Selected, Vigor Rating, and Brix by Family Across 251 (in 2009) and 263 (in 2010) Families Yielding 1,423 and 1,501 Clones Selected, Respectively, in 2009 and 2010 in the Canal Point (CP) Sugarcane Cultivar Development Program†

	2009				2010			
Parameter	Clones selected (No. family^{-1})	Vigor	Brix	Vigor × brix	Clones selected (No. family^{-1})	Vigor	Brix	Vigor × Brix
Max	48	8.2	23.0	168.0	40	8.0	23.0	176.0
Min	1	6.0	17.0	117.0	1	6.0	16.3	114.3
Mean	5.7	7.0	19.5	135.6	5.7	6.7	19.5	129.1
SD	6.5	0.5	1.0	8.6	5.7	0.5	1.1	7.1
CV (%)	114	7.6	5.0	6.3	99	6.8	5.8	5.5

†Based on their elevated vigor ratings (vigor ≥6), 2,355 and 2,593 clones in 299 and 292 families were used for collecting Brix data in 2009 and 2010, respectively.

TABLE 5 Number of Total Sugarcane Clones Planted, Clones Selected (Selection Rate), Vigor, Brix, and Their Parents for the 20 Families with the Highest Selection Rates Using 165 Families with ≥15 Clones in Stage I of the Canal Point (CP) Sugarcane Cultivar Development Program in 2009

Family	No. of clones	Selection rate (%)	Vigor†	Brix	Parents	
					Female	Male
06-0041	20	50.0	7.1	19.9	CP 00-1301	Poly 06-3
06-1296	46	47.8	7.1	19.9	CP 01-2390	Poly 06-50
06-1011	19	42.1	7.0	19.4	CL 02-8021	Poly 06-35
06-0240	24	41.7	8.0	18.1	CP 03-1026	HoCP 00-930
06-0888	27	40.7	7.5	19.0	CL 89-5189	Poly 06-30
06-0664	42	40.5	7.6	19.6	CL 89-5189	CP 01-2390
06-0818	15	40.0	6.5	20.8	TCP 01-4535	CP 01-2390
06-0498	21	38.1	6.8	19.9	CP 03-1094	Poly 06-21
06-0373	16	37.5	7.0	19.2	CL 90-4725	CP 00-2188
06-0857	27	37.0	7.4	19.1	CPCL 96-4974	CP 01-2459
06-0794	117	35.9	7.2	20.0	CP 01-2459	CL 02-8021
06-0488	38	34.2	7.2	18.8	CPCL 00-6756	Poly 06-20
06-0369	85	34.1	7.2	19.1	CP 84-1198	CL 89-5189
06-0667	39	33.3	6.9	20.1	CPCL 96-4974	CP 01-2390
06-0570	21	33.3	6.9	20.0	CP 03-1160	CP 00-2188
06-0585	21	33.3	6.4	20.0	CPCL 96-4974	CP 00-1751
06-0998	76	32.9	7.5	18.9	CP 03-1094	Poly 06-35
06-0737	146	32.9	7.3	19.1	CP 01-2459	Poly 06-26
06-0941	63	31.7	7.3	19.9	CP 01-2390	Poly 06-32
06-1001	41	31.7	7.5	19.6	CP 97-1777	Poly 06-35
Mean	45 (41)‡	37.4 (18.7)	7.1 (7.0)	19.5 (19.6)		
Max	146 (167)	50.0 (50.0)	8.0 (8.2)	20.8 (23.0)		
Min	15 (15)	31.7 (3.4)	6.4 (6.0)	18.1 (17.3)		
CV (Among)	79 (64)	13.9 (54.1)	5.2 (6.9)	3.5 (4.4)		
CV (Within)§			11.3 (10.1)	6.9 (6.2)		

†Clones with vigor rating ≥6 were used for Brix. Therefore, data of vigor <6 were not included.
‡The first values are calculated based on the top 20 families, and the second values within parentheses are based on all 165 families with ≥15 clones planted.
§CVs within family are means of individual family CVs in the top 20 or means of all 165 families.

that at least 10 to 20 clones per family were required for evaluation of high-performing sugarcane families. Therefore, the families with ≥15 clones were ranked based on their selection rates, and the top 20 families were identified (Tables 5 and 6). Overall, there was much greater variability in the number of clones and in selection rate than in vigor and Brix among families. The vigor ratings and Brix values of these families (Tables 5 and 6) were greater than those of the check cultivars (Table 1). The CVs within family for both vigor and Brix were greater than CVs among families (Tables 5 and 6). Parents of the top 20 families could provide useful information on crossing combinations. For instance, genotype CP 01-2390 should be a favorable parent for developing plants with high yield potential because it was a parent of several families that ranked in the top 20 in both years (Tables 5 and 6).

TABLE 6 Number of Total Sugarcane Clones Planted, Selection Rate, Vigor, Brix, and Their Parents for the 20 Families with the Highest Selection Rates Using 176 Families with ≥15 Clones in Stage I of the Canal Point (CP) Sugarcane Cultivar Development Program in 2010

Family	No. of clones	Selection rate (%)	Vigor†	Brix	Parents	
					Female	Male
07-1062	56	71.4	7.3	19.7	CP 01-2390	TCP 98-4454
07-1270	32	62.5	6.9	20.7	CP 01-2390	Mix 07 Q
07-1380	37	56.8	6.7	20.0	CP 01-2390	Mix 07 W
07-959	18	55.6	7.2	20.1	CP 01-2390	Mix 07 D
07-1299	46	50.0	7.3	18.6	CP 00-1751	Mix 07 S
07-1095	34	50.0	7.1	19.0	CP 03-1912	Mix 07 J
07-1301	41	39.0	6.6	19.9	CP 01-2390	Mix 07 S
07-795	41	39.0	6.9	18.9	CP 98-1029	US 02-0099
07-879	42	38.1	7.2	18.3	CP 92-1167	POLY 07-08
07-1268	76	36.8	7.2	19.3	CP 00-2164	Mix 07 Q
07-1050	49	36.7	6.8	19.4	CP 03-1912	Mix 07 H
07-1099	59	35.6	6.9	19.5	CPCL 99-1371	Mix 07 J
08-669	17	35.3	7.5	17.6	L 05-448	HoCP 05-918
07-834	37	35.1	7.0	19.2	CP 00-1074	POLY 07-04
07-1121	20	35.0	7.1	19.1	TCP 04-4720	CPCL 00-6131
07-1079	86	34.9	6.6	19.9	CP 98-1029	Mix 07 I
07-1298	30	33.3	7.1	17.9	CP 01-1391	Mix 07 R
07-1087	37	32.4	7.2	19.1	CL 89-5189	Mix 07 J
07-1023	22	31.8	6.7	19.6	CP 01-2390	Mix 07 F
07-836	41	31.7	7.2	19.8	CP 01-2390	POLY 07-04
Mean	41 (41)‡	42.1 (18.5)	7.0 (6.7)	19.3 (19.4)		
Max	86 (149)	71.4 (71.4)	7.3 (8.0)	20.7 (22.0)		
Min	17 (15)	31.7 (2.2)	6.6 (6.0)	17.9 (16.3)		
CV (Among)	44 (54)	27.3 (61.9)	3.5 (5.8)	3.9 (5.0)		
CV (Within)§			10.9 (8.4)	6.7 (6.5)		

†Clones with vigor rating ≥6 were used for Brix. Therefore, data of vigor <6 were not included.
‡The first values are calculated based on the top 20 families, and the second values within parentheses are based on all 176 families with ≥15 clones planted.
§CVs within family are means of individual family CVs in the top 20 or means of all 176 families.

CP 01-2390 was not released for commercial use because of its susceptibility to smut even though it had superior cane and sugar yields (Glaz et al. 2007). Therefore, crossing of CP 01-2390 with smut-resistant clones should be emphasized to generate new agronomically desirable combinations.

Chang and Milligan (1992) evaluated 1,800 progeny from 15 crosses for genetic gain using replicated plots and concluded that the gains were consistently larger for an initial 50% family selection and subsequent 20% individual selection than they were for simple individual selection at a 10% selection intensity. Shanthi et al. (2008) also reported that selection of the best families based on their mean performance and further selection of individual clones based on their sugar yield in early stages would improve the efficiency of selection and increase heritability in the genetic populations tested. However, application of complete family selection in a sugarcane breeding program usually requires more time, resources, and special equipment to measure yields (McRae et al. 1993; Jackson, McRae, & Hogarth 1995a,b). In the present study, it was not feasible to directly determine yields by harvesting the more than 8,500 individual plots (clones) planted annually in stage I. Use of more than one replicate in stage I of the CP program is also impractical because of land and labor limitations.

Additionally, when mean vigor for each family with ≥15 clones was calculated on the basis of data we collected using individual selection, the family mean vigor rating was highly correlated with its selection rate each year ($r = 0.72$, $n = 165$, and $P < 0.0001$ for 2009; $r = 0.70$, $n = 176$, and $P < 0.0001$ for 2010). If the initial 50% of families in stage I had been dropped based on the family mean vigor as recommended by Chang and Milligan (1992), we would have lost 6% and 9% of the families, respectively, in 2009 and 2010, which had higher selection rates than the selection rate of the overall family mean. In addition, more than 30% of selected clones would not have been included in the present study (data not shown). Zhou (2005) reviewed early stage selection of sugarcane and suggested that a 50% rate of family selection would discard 36% of elite clones. The evaluation of superior families would require use of increased resources and may require an increase in length of time for the selection program with a large loss of potentially superior clones. Selection procedures and specific selection strategies of sugarcane cultivar development programs should depend on goals, resources, and environmental conditions. The degree of family selection recommended by previous studies (Chang & Milligan 1992; McRae et al. 1993; Shanthi et al. 2008) may not be appropriate for the CP program because of unique environmental conditions and limited resources.

Quantitative analyses of sugarcane clonal data collected in stage I of the CP cultivar development program could help us evaluate not only crosses (families) but also their parents as described above. Studies have suggested that family selection is effective in improving sugarcane populations in early selection stages (Chang & Milligan 1992; Cox & Hogarth 1993; McRae et al. 1993; Shanthi et al. 2008) because it can identify those families that harbor the highest proportion of desirable clones and makes it possible to focus selection for superior clones (Shanthi et al. 2008). Availability of family data helps sugarcane breeders improve cross combinations by identifying the most successful parents. In an earlier report, Jackson, McRae, and Hogarth (1995a) suggested that individual clone selection was superior only in cases where there was both a small proportion of the among-family variance and a high genetic correlation between the selected trait and sugar yield. Family selection is particularly useful and superior to individual selection in situations where family × environment interaction, especially soil nutrient status, is important (Jackson, McRae, & Hogarth 1995b). As mentioned earlier, Canal Point has favorable and predictable weather and a uniform organic soil for sugarcane breeding and growth. Therefore, the family × environment interaction should be relatively small, and individual selection in stage I may be appropriate or superior to family selection under our conditions. The fact that the CVs within family were greater than the CVs among families for both vigor and Brix indicated that if we completely relied on family selection in the CP sugarcane cultivar development program, we would lose a considerable number of elite clones from the rejected families. These results lend further support to our stage I individual selection approach at Canal Point.

CONCLUSIONS

Early stage selection methods and specific selection strategies of sugarcane cultivar development programs are dependent on environmental conditions and the unique goals and resources of each selection program. Analyses of vigor and Brix data from individual selections of stage I of the CP sugarcane cultivar development program revealed that it is feasible in the early stage to select sugarcane clones with both high vigor and high Brix. Our data indicated that placing more emphasis on family-based rather than individual selection in stage I would result in the loss of potentially productive clones. However, use of our individual selection data on vigor and Brix for making comparisons of family performance and the among- and within-family variability would improve our parental selection and optimize crosses among selected parents, which should then improve the quality of future stage I plantings. One clone in particular, CP 01-2390, was identified as a valuable parent for the CP program.

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